VII. CHARACTERIZATION OF OPEN BAY BENTHIC ASSEMBLAGES OF THE GALVESTON ESTUARY AND ADJACENT ESTUARIES FROM THE SABINE RIVER TO SAN ANTONIO BAY

Donald E. Harper, Jr.

INTRODUCTION

With the inception of the Galveston Bay National Estuarine Program, the need for long-term data sets has become critical. Managers need to know what "was" before they can begin to assess the types and magnitude of changes that have occurred in the Galveston Bay System. Long-term data sets for benthos are, by and large, lacking. Many graduate students have conducted one-year studies in various parts of the bay, as have researchers intent on documenting the environmental effects of one or more types of pollution. Funding agencies, however, typically allot one, two, or perhaps three years of study to ecological projects, which does not give the investigator sufficient time to dissect background "noise" out of the data, much less allow the examination of long-term trends. To date, there have been no efforts to identify or assimilate these discrete studies into an overall data base for the bay system. This report attempts to rectify that situation and draw conclusions as to the seasonal trends, interannual differences and geographic distribution of the macrobenthos and abiotic characteristics.

MATERIALS AND METHODS

A search was made of holdings in the author's personal library, and libraries at Texas A&M University at Galveston, Texas A&M University at College Station, Rice University, University of Houston (including U.H.-Clear Lake), University of Texas, and the National Marine Fisheries Service, Galveston. Published literature, unpublished research reports, and theses and dissertations held in university libraries were located via on-line computer searches of library holdings to obtain a comprehensive list of data sets pertaining to soft bottom (mud, sand, mixed bottoms), open water (i.e. non-marsh) benthic assemblages in the Galveston Estuary. In addition, Texas Water Commission personnel were interviewed to ascertain the status of benthic data not yet analyzed.

An annotated bibliography was prepared listing each reference found. Annotations include items such as: period and location of study, collecting and preservation methods, sample and data analysis techniques, type of data reported, archival status of samples and data (if known). An abstract was prepared for each citation which listed the dominant species and briefly described the seasonal trends in temperature, salinity, and other abiotic characteristics measured, and abundance trends of the infauna.

The data presented herein pertain only to level bottom macrobenthic assemblages (usually defined as those benthic organisms retained on a 0.5 mm mesh sieve). No data on oyster reef assemblages or meiobenthos have been included.

RESULTS AND DISCUSSION

History of Investigations of Macrobenthic Assemblages

The earliest studies of "benthic" organisms were commercially-driven surveys of oyster reefs in Texas estuaries. Rathburn (1895) conducted the earliest oyster reef survey. Moore (1907) surveyed the oyster bottoms in Matagorda Bay in 1905, and subsequently (1913) in Lavaca Bay (Moore and Danglade 1915). Hopkins (1931) studied factors influencing the spawning and settling of oysters in Galveston Bay. Galtsoff (1931) surveyed oyster bottoms in Texas estuaries in 1926. The overall molluscan fauna was also reasonably well known, with species lists having been compiled by Johnson (1934) and Pulley (1952), but relatively little was known about the other taxa inhabiting bay bottoms. No quantitative studies were undertaken prior to 1950 (Hedgpeth 1954).

The next phase of macrobenthic studies, which began in the early 1950s, consisted of defining "communities" in relation to environmental factors (temperature, salinity, substrate). This research was largely driven by petroleum geologists' need to understand which fossil assemblages were associated with what environmental conditions. The "communities" described consisted predominantly of molluscan species, the shells of which preserve well (Ladd 1951, Ladd, Hedgpeth and Post 1957, Parker 1959, Parker 1960). These studies also concentrated more on south Texas estuaries and offshore bottoms than the Galveston Estuary area.

Beginning about 1970, biologists began studying infaunal assemblages in detail, usually in response to concerns about the effects of a particular pollutant, or the total pollutants in a general area. Quantitative samples were collected using several types of sampling devices, and the total assemblage was analyzed. Abiotic data, such as temperature, salinity, dissolved oxygen and sediment characteristics, were collected, allowing the investigators to determine the influence of these factors on populations or assemblages. Many of these studies were conducted over a period of a year or more, and many overlapped temporally, allowing some assessment of seasonal changes in species composition and abundance.

Sampling Methods Used by Investigators

Comparison of the data sets is complicated because various investigators have used different sampling devices and techniques. While the majority of studies reviewed have used Ekman grab samplers, the Peterson grab, Ponar grab, Jackson volumetric sampler, Emory sampler, orange peel grab, spade corer, coring tube, and dredges were also used. The surface area sampled by the quantitative devices (i.e. excluding dredges) ranged from 20.25 cm^2 to 0.25 m^2. Because of the array of sampler sizes, it is not possible to directly compare diversity among studies, although numbers of individuals may be compared by extrapolating raw numbers to numbers per m^2 (extrapolation factor range = 4 to 494).

The majority of investigators washed their samples on 0.5 mm mesh sieves, but sieve sizes used ranged from 2.0 mm to 0.25 mm. The sieve size can drastically alter the data collected; many of the macrobenthic species are small and pass through larger mesh sizes. This was documented by Armstrong et al. (1977, 1979) when the investigators switched from a 0.5 mm to a 0.25 mm mesh sieve in mid-project and obtained 20-40 times more organisms per sample because smaller infauna such as nematodes, rotifers and copepods (which are usually classified as meiofauna) were collected in large numbers.

The number of replicate samples collected was most frequently 3, with a range of 1 to 5. Attempts to determine within-site variability and to determine the optimum sample number necessary to estimate benthic abundances were made by Harper (1973) offshore from Galveston, and in Matagorda Bay by Shipley (1987). At the offshore site, it was determined that optimum sample numbers ranged from 6 (soft clay) to >10 (sand and sand-mud). In Matagorda Bay (soft clay) the optimum sample number was 6.

Most investigators sieved samples in the field to remove sediments and then fixed samples in formalin (5 to 10%). In a few projects, most notably the long-term study of the Cedar Bayou power plant (Williams 1972, Poff 1973, McBee 1975) and in Gillard's (1974) study of Upper Galveston Bay, the entire sample was placed in a bucket and returned to the laboratory where it was washed with fresh water before being placed in formalin. It has been the author's experience that delaying fixation and washing with fresh water may result in soft-bodied organisms (e.g. polychaetes, nemerteans) swelling or bloating and not fixing properly, making subsequent identification more difficult.

Areas Sampled Within the Galveston Estuary

Studies conducted within the Galveston Estuary, and in nearby bays, are listed by estuary in Table VII.1. Most studies were concentrated in Trinity Bay-Upper Galveston Bay, or in West Bay. Figure VII.1 depicts the portions of the Galveston Estuary sampled during investigations of discrete portions of the system, and Figure VII.2 depicts the time spans of these studies. From 1969 to 1975, Trinity Bay and Upper Galveston Bay benthic assemblages were sampled extensively in relation to general ship channel pollution (Gillard 1974), thermal pollution (Williams 1972, Poff 1973, McBee 1975), and oilfield brine pollution (Mackin 1971, Armstrong et al. 1977, 1979). Several areas in West Bay (including bayous opening into West Bay) were sampled from 1976 to the present (Potts 1978, Fort 1983, Dent 1983, Nance 1984, Walker unpub., Harper unpub.).

Areas Sampled in Adjacent Estuaries

Studies in adjacent estuaries are listed in Table VII.1 and the time spans are shown in Figure VII.3. In the Sabine River area, Harrel et al. (1976) investigated the effects of construction and removal of the Neches River barrier (no quantitative data included), and Wern (1980) attempted to determine if pollutants were being carried into Sea Rim State Park.

Table VII.1. Macrobenthos studies conducted in the Galveston Estuary and adjacent bay systems arranged by location.

GALVESTON ESTUARY STUDIES

GALVESTON ESTUARY-WIDE STUDIES
- Parker 1960
- Bechtel, Copeland and Whitefield 1970.
- Holland, Masciolek and Oppenheimer 1973
- White et al. 1985
- Texas Water Commission (unpub.)

TRINITY BAY STUDIES
- Mackin 1971
- Williams 1972
- Poff 1973
- Strawn et al. 1974
- McBee 1975
- Armstrong et al. 1977, 1979

UPPER GALVESTON BAY STUDIES
- Gillard 1974

LOWER GALVESTON BAY STUDIES
- Wardle 1970
- Harry 1976

WEST BAY STUDIES
- Ray 1978 (unpub.) (New Bayou)
- Potts 1978 (Eckert Bayou)
- Ray 1979 (unpub.) (Halls Bayou)
- Fort 1983 (Laguna del Oro)
- Dent 1983
- Nance 1984 (New Bayou)
- Ray, Harper and Webb 1985 (unpub.)
- Mayfield 1988
- Landry et al. 1990
- Walker (unpub.) (Eckert Bayou)
- Harper (unpub.) (Eckert Bayou)
- Harper (unpub.) (Highland Bayou Diversionary Canal)

BOLIVAR ROADS STUDIES
- Henry 1976

CHRISTMAS BAY
- Conte and Parker 1971
- Craig and Bright 1986

Table VII.1. (continued)

ADJACENT ESTUARY STUDIES

SABINE RIVER AREA
- Harrel et al. 1976 (Sabine River)
- Ray (unpub.) (Sea Rim State Park)
- Wern 1980 (Sea Rim State Park)

LAVACA AND MATAGORDA BAYS
- Shenton 1957
- Marland 1958
- Mackin 1971
- Harry and Littleton 1973
- Gilmore et al. 1976
- Woodward-Clyde 1977

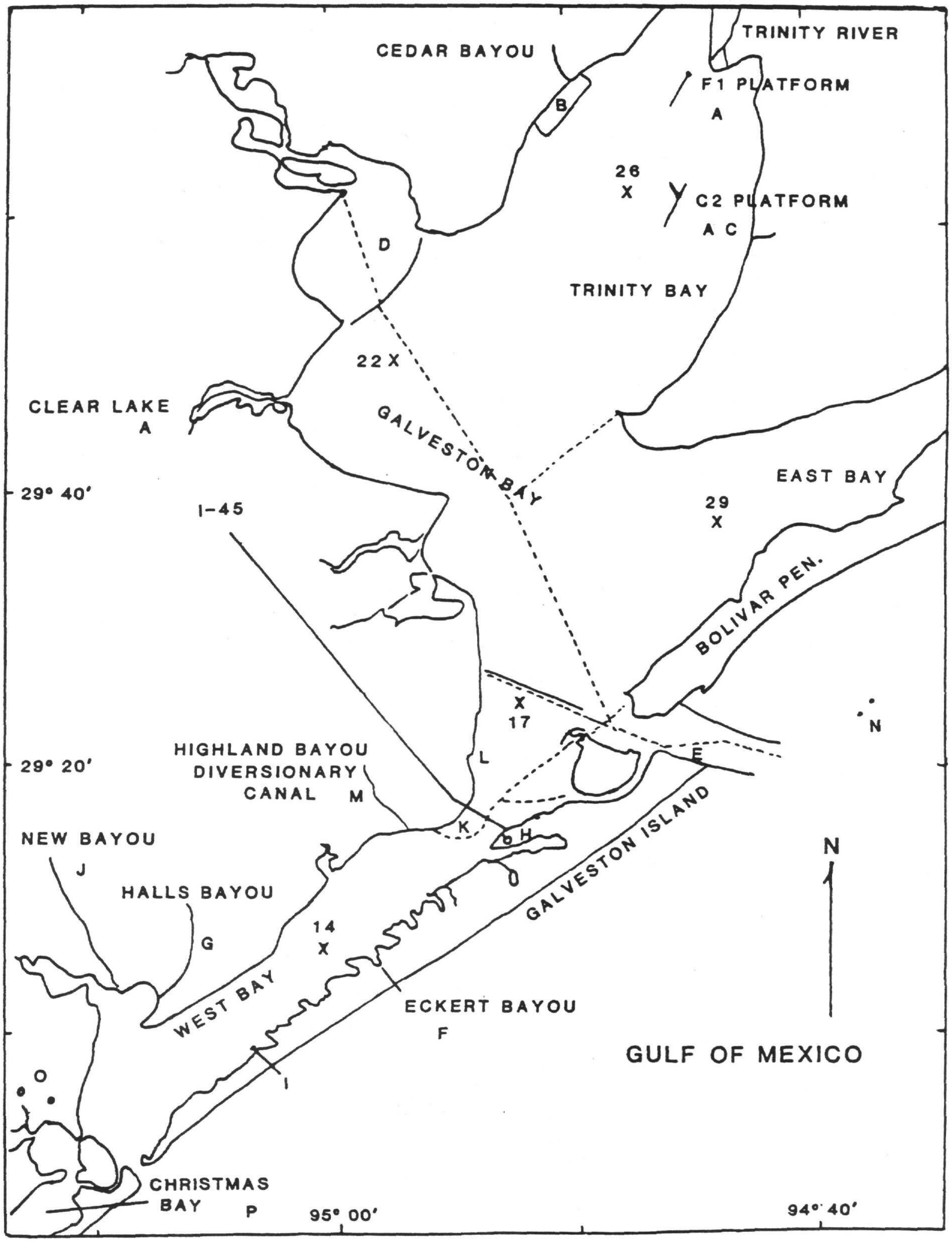
SAN ANTONIO BAY
- Matthews and Marcin 1973
- Matthews, Marcin and Welsh 1974
- Harper and Hopkins 1973, 1976

Macrobenthic studies in the Lavaca-Matagorda Estuary pertained to oilfield brine pollution (Mackin 1971), effects of thermal effluent discharge (Moseley and Copeland 1971) and effects of freshwater inflow (Gilmore et al. 1976). Non-quantitative studies of the areal distribution of specific groups were conducted by Shenton (1957; foraminiferans), Marland (1958; mollusks, large crustaceans), and Harry and Littleton (1973; mollusks, ostracods).

San Antonio Estuary macrobenthos were studied in relation to freshwater inflow (Matthews and Marcin 1973, Matthews et al. 1974) and effects of oyster shell dredging (Harper and Hopkins 1973, 1976).

Areal Distributional Patterns of Macrobenthic Assemblages in the Galveston Estuary

Estuary-wide studies of infaunal organisms have generally been conducted in one of two ways: stations are closely spaced and no seasonal data are collected, or a few stations representative of the estuary are sampled quarterly to monthly. The former studies are invaluable for determining the sediment composition over the entire bay (which will change relatively slowly over time), but are of limited usefulness for determining biotic communities, because: (1) several months may be required to collect the samples, and during the time required to complete this undertaking, the benthic organisms' abundances and species composition almost certainly change, sometimes dramatically, in response to changes in temperature or the salinity regime; for example, Harper and Hopkins (1973, 1976) collected benthic samples monthly throughout San Antonio Bay and documented rapid changes in populations of species during and following a major flood



CEDAR BAYOU
TRINITY RIVER
F1 PLATFORM
A
B
26
X
C2 PLATFORM
A C
D
TRINITY BAY
22 X
CLEAR LAKE
A
GALVESTON BAY
EAST BAY
29° 40'
I-45
29
X
BOLIVAR PEN.
X
17
N
HIGHLAND BAYOU
DIVERSIONARY
CANAL
M
L
29° 20'
E
K
H
NEW BAYOU
J
GALVESTON ISLAND
N
HALLS BAYOU
G
14
X
WEST BAY
ECKERT BAYOU
F
GULF OF MEXICO
O
I
CHRISTMAS
BAY
P
95° 00'
94° 40'

on the Guadalupe River; (2) rapid collection of all samples by several field crews provides a "snapshot" of assemblages at one point in time. In the latter type of study, sampling occurs more frequently at fewer stations allowing comparison of temporal trends within an estuary, but spatial coverage is very limited.

Two major estuary-wide surveys have been conducted in the Galveston Estuary, one by Parker (1960) and one by the Bureau of Economic Geology (White et al. 1985). White et al. (1985) collected single core samples on one-mile centers throughout the Texas bay systems and in the nearshore shallow waters in the open Gulf. Parker (1960) used van Veen and orange peel grabs, and samples were washed on a 1-mm sieve. There was no indication of replicate sampling. Parker defined several macrofaunal assemblages, based mostly on mollusks, in relation to salinity and substrate characteristics. White et al. used most of the same assemblage categories delineated by Parker, but used all taxa of benthic organisms in establishing assemblages. Another difference between the surveys is that while Parker (1960) depended to some extent on the reports of Galtsoff (1931), Pulley (1953), and Reid (1955) in delineating his assemblages and their habitats, he sampled during the "7-year drought" that occurred in Texas from 1950-1957. During this time, river discharge decreased and salinities in the estuary increased (in July and August 1954, average maximum salinities were 37.1 and 37.5 ppt, respectively, at the Galveston Channel monitoring station; Harper 1977). Salinities were lower during the Bureau of Economic Geology sampling program (White et al. 1985).

White et al. (1985) found that Polychaeta, Mollusca and Crustacea were the dominant taxa. The largest numbers of polychaetes occurred in muddy bottoms while crustaceans were most abundant on sandy bottoms.

Figure VII.1 (opposite). Map of the Galveston Estuary showing areas referred to in the text or appendices.

A. Mackin 1971, Williams 1972, Poff 1973, Strawn et al. 1974, McBee 1975
C. Armstrong et al. 1975
D. Gillard 1974
E. Wardle 1970
F. Potts 1978, Walker unpub., Harper unpub.
G. Ray (1979) unpub.
H. Fort 1983
I. Dent 1983
J. Nance 1984, Ray (1978) unpub.
K. Mayfield 1988
L. Landry et al. 1990
M. Harper unpub.
N. Henry 1976
O. Conte and Parker 1971
P. Craig and Bright 1985
X. Holland, Maciolek and Oppenheimer 1973 (numbers are station numbers)

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YEAR    J    F    M    A    M    J    J    A    S    O    N    D

1969                                              |--Williams---
1970    -----------------Williams------------------------------|
                                        |----Gillard------------
                                               |---Mackin-------
1971    -----------------Gillard--------------------------------
        ---------------------------------Mackin----------------|
        |----Poff-----------------------------------------------
1972    ---Gillard--|
        --------Poff-----|-----x         x------McBee-----------
1973    ----------------McBee--------------|
1974                |-------------Armstrong et al.--------------
1975    --------------------Armstrong et al.-------------------|
                         |----------------Henry-----------------
1976    -----Henry-------|            |----------Potts----------
1977    ----Potts---------------------|---Walker----------------
1978    --------------Walker--------|- Harper (unpub)^1----------
1979    ---------------------Harper (unpub)^1-------------------
1980    ------------Harper (unpub)^1-----------------------------
                          |---------Nance-----------------------
                                    |-----Fort------------------
                                    |Dent
1981    --------------Harper (unpub)^1---------------------------
        -----------Nance------------------------|
        --------------------Fort----|
        ----------Dent-----------------------------------------|
1982    ----------Harper (unpub)^1-------------------------------
1983    -------------------Harper (unpub)^1---------------------
1984    ---------Harper (unpub^1)----------------------------x
1985
1986       |------------Harper (unpub)^2------------------------
1987    -----Harper (unpub)^2---|
1988
1989
1990                                         x--Harper(unpub)^1--
1991    ------------------Harper (unpub)^1----------------------
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Figure VII.2. Duration of monthly or semimonthly macrobenthic assemblage sampling programs at discrete localities within the Galveston Estuary, 1969-1991.
| = start or stop of sampling program; ---x x--- = data gap
Harper (unpub): 1 - Eckert Bayou; 2 - Highland Bayou Diversionary Canal

SABINE RIVER AREA

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YEAR    J    F    M    A    M    J    J    A    S    O    N    D
1970                        |--------Harrel et al.---------------x
1971                                   x-------Harrel et al.-----
1972    ------------Harrel et al.-------------|
1973
1974
1975
1976
1977
1978                                         |-----Wern---------
1979    ---------------------------Wern-----|

                   ----x   x----- = data gap
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LAVACA BAY-MATAGORDA BAY AREA

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YEAR    J    F    M    A    M    J    J    A    S    O    N    D
1969                   +              +              +
1970    +              +              +              +
                                              |------Mackin------
1971    +
        --------------------Mackin------------------|
1972
1973    |------------Gilmore et al.-----------------------------
1974    -------------Gilmore et al.-----------------------------
1975    -------Gilmore et al.------|

              +  = Moseley and Copeland quarterly data
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SAN ANTONIO BAY AREA

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YEAR    J    F    M    A    M    J    J    A    S    O    N    D
1972             |----------------Harper and Hopkins------------
                    |--Matthews and Marcin--|--Matthews et al.--
1973    --H&H---|
        -----------Matthews et al.------|
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Figure VII.3. Duration of monthly or semimonthly macrobenthic assemblage sampling programs at discrete localities within bay systems adjacent to Galveston Bay, 1969-1979.

The soft bottom assemblages, based on Parker (1960), White et al. (1985), personal observation and other studies cited below (with annotations), include:

River-influenced, low salinity assemblage: Salinity < 10 ppt. Usually found in upper and middle portions of bays with permanent river mouths.

Rangia cuneata (Bivalvia) - This clam is very abundant in beds, usually fairly close to river discharges. Isolated populations, however, may be found in higher salinity areas. Rangia's reproductive physiology requires salinity to rise above near 0 ppt or to decrease below 15 ppt to induce gametogenesis (Hopkins, Anderson and Horvath 1973). A major flood may induce gametogenesis and allow larvae to survive and metamorphose downbay and establish a population of adult animals as was found along the Intracoastal Waterway in San Antonio Bay (Harper, unpub.). These adults are thus indicators of former, not necessarily current, salinity conditions.
Rangia flexuosa (Bivalvia) - Not as common as R. cuneata.
Macoma mitchelli (Bivalvia) - Most authors regard this species as indicative of low salinity (Harry 1976), but Nance (1984) and Landry et al. (1990) found it to be a member of marine or estuarine assemblages.
Texadina (=Littoridina sphinctostoma) (Gastropoda)
Vioscalba louisianae (= Probythinella protera)(Gastropoda)
Streblospio benedicti (Polychaeta)
Mediomastus ambista (Polychaeta)
Hobsonia florida (=Hypaniola gunneri floridus = Amhicteis gunneri) (Polychaeta) - This is a good indicator of recent flood conditions in a bay system. Hobsonia apparently thrives in very low salinity (Ray unpub.)
Tubificioides heterochaetus (Oligochaeta)
Peloscolex gabriellae (Oligochaeta)
Macrobrachium spp. (Crustacea) - Usually only found in the bay when the salinity is very low, i.e. following a flood.
Chironomidae (Insecta) - Chironomids may be very abundant in low salinity assemblages.

Enclosed bay or interreef assemblage (not recognized by White et al. 1985 as a separate assemblage, but included with open bay assemblage): Varying temperatures, salinities and bottom composition. Organisms tend to be tolerant of environmental change.

Nuculana acuta (Bivalvia)
Nuculana concentrica (Bivalvia)
Mulinia lateralis (Bivalvia)
Tagelus plebeius (Bivalvia)
Ensis minor (Bivalvia)
Acteocina (=Retusa) canaliculata (Gastropoda)
Streblospio benedicti (Polychaeta)
Mediomastus ambiseta (Polychaeta)
Microphiopholis atra (= Amphiodia limbata) (Ophiuroidea)

Open bay assemblage: Salinity range 20-35 ppt, temperature range 8-36 C, sediments predominantly silty clay to clayey silt.

Abra aequalis (Bivalvia)
Corbula contracta (Bivalvia)
Mulinia lateralis (Bivalvia)
Nuculana concentrica (Bivalvia)
Pandora trilineata (Bivalvia)
Periploma orbicularis (Bivalvia)
Acteocina canaliculata (Gastropoda)
Paraprionospio pinnata (Polychaeta) - much more abundant offshore, but does invade lower bay when salinity conditions are favorable.

Bay margin assemblage: Shallow, sandy bottoms.

Ensis minor (Bivalvia) - Deeper burrowing form. May not be collected unless young.
Heteromastus filiformis (Polychaeta)
Streblospio benedicti (Polychaeta)
Mediomastus ambiseta (Polychaeta)
Capitella capitata (Polychaeta)
Ampelisca abdita (Crustacea) - Especially abundant where detritus is present (Potts 1977, Walker unpub.).
Corophium louisianum (Crustacea)
Hargeria rapax (= Leptochelia dubia) Crustacea)

Inlet and deep channel assemblage: Salinity usually near-Gulf, temperature more stable than in shallower areas, sediments sand and shelly sand.

Nassarius acutus (Gastropoda) - The most abundant species on nearshore Gulf bottoms in the Galveston area (Harper 1970)
Tellina texana (Bivalvia)
Owenia fusiformis (Polychaeta) - Abundant on nearshore Gulf bottoms in the Galveston area (Harper 1970).
Onuphis eremita oculata (Polychaeta) - Abundant on nearshore Gulf bottoms in the Galveston area (Harper 1970).

Some polychaetes listed as characteristic of more than one assemblage by White et al. (1985) are nearly ubiquitous in the estuaries, i.e. Mediomastus ambiseta (reported in most studies as M. californiensis, which is an offshore species) and Streblospio benedicti, or widespread, i.e. Paraprionospio pinnata. Harper (1973) and Harper and Hopkins (1976) found Mediomastus and Streblospio most abundant at salinities of 12.5 ppt and 10-12 ppt, respectively, while Nance (1984) found both species to be most abundant at > 24 ppt.

The reader must be aware that these assemblages are not static and that there are no "boundary lines" separating one assemblage from another. At any point in time these assemblages intergrade into one another along a salinity and sediment gradient. Also, any given portion of the bottom may have an Open Bay assemblage one year and a River Influenced assemblage the next year, depending on salinity conditions. This was well documented by Harper and Hopkins (1973, 1976) in San Antonio Bay and by Nance (1984) in New Bayou. Both conducted studies preceding, during, and following major flooding events. Thus, within the Galveston Estuary, the assemblage "boundaries" described by Parker (1960) do not correspond with the boundaries described by White et al. (1985) based on more recent data collected when salinities were lower.

Temporal Distribution Patterns of Macrobenthic Assemblages

Most of the studies reviewed reported a unimodal abundance pattern for the macrobenthos, with the peak occurring in the spring, usually between February and May, depending on the year and location of the study. In a few instances, a bimodal abundance pattern was reported, with the second maximum occurring in the fall. Most studies, however, indicated that macrobenthic abundances decline through the summer and reach a nadir in the September-November period of the year before beginning to increase again. Interannual differences occur not only in the timing of peak abundances, but also in the total numbers attained. Analysis of within-season variability by Harper and Nance (1985) following a seven-year study of the macrobenthos offshore from Freeport indicated that the greatest variability in total abundance occurred in the winter quarter (February) and the smallest variability occurred in the fall quarter (November).

Temperature is probably the primary abiotic factor controlling the seasonal cycle; many of the abundant macrobenthic species appear to be spring spawners and may produce several cohorts (cf. Mayfield 1988). Salinity can, however, alter the seasonal cycle.

Mediomastus ambiseta and Streblospio benedicti were most frequently the numerically dominant species in the Galveston Estuary and in adjacent systems. The populations of these species may be so large that they control the abundance trends of the entire assemblage at a particular site.

Trinity Bay-Upper Galveston Bay Studies

Three major studies were conducted in the Trinity Bay-Upper Galveston Bay area between 1969 and 1975: the Houston Power and Light Cedar Bayou power plant (HL&P) project (Williams 1972, Poff 1973, McBee 1975), the Upper Galveston Bay pollution study (Gillard 1974), and the Humble Oil Company (now Exxon) brine separator study (Mackin 1971, Armstrong et al. 1977, 1979). All three studies used Ekman grabs (or a modified version thereof), but the sieve sizes varied. A 0.82 mm sieve was used on the HL&P project, whereas Gillard and Mackin used a 0.5 mm sieve and Armstrong et al. used a 0.5 mm sieve until December 1974 and then switched to a 0.25 mm mesh sieve.

Salinities in the area were < 10 ppt in the latter part of 1969 through July 1970 (Williams 1972). Salinities increased to 11-15 ppt in September-October 1970, then decreased briefly to 3-7 ppt in November before increasing to about 13 ppt by December 1970. Macrobenthic abundances were low in 1969 through most of 1970 (Figures VII.4, VII.5; note that all abundance scales in this series of figures are based on a maximum of 14,000 ind/m^2 for consistency). Mediomastus ambiseta was the numerical dominant during most of this period. Vioscalba louisianae was dominant in May. Abundance trends reported by Mackin (1971) were similar, but absolute abundances were higher, possibly because of the larger sieve size used on the HL&P study. Mackin found that Peloscolex gabriellae (Oligochaetea) was the numerical dominant between September and December Mediomastus ambiseta and Streblospio benedicti were secondary dominants.

In 1971, salinities increased from 13 ppt in January to the 20-22 ppt range through November. In December salinities decreased to 5 ppt. A well-defined macrobenthic spring peak occurred in March-April (Figure VII.6). Mediomastus ambiseta was the numerical dominant during the HL&P study except during the period September-December, when a set of Mulinia lateralis caused this bivalve to become numerically dominant. Mackin (1971) reported that Mediomastus ambiseta, Streblospio benedicti and Peloscolex gabriellae were the dominants. Mulinia lateralis was abundant between April and August.

In 1972, salinities were < 5 ppt from January to March. Salinities increased to 11 ppt in April and decreased again to 5 ppt in May (Figure VII.7). Mediomastus was the numerical dominant during the HL&P study. During the latter part of 1972 and early 1973 (Figure VII.8), the macrobenthic abundance peak occurred in January.

The number of individuals collected during the HL&P project were usually less than 4,000/m^2. Inclusion of all HL&P data, using a smaller abundance scale, clearly shows the recurrent spring peaks (Figure VII.9) and demonstrates the variable time of peak occurrence and the variable maximum number of individuals.

In 1974, during the Armstrong et al. (1977, 1979) brine discharge study at the Exxon C2 platform, salinities were low much of the time, and were 1.0 ppt or less during spring 1975 (Figures VII.10, VII.11). Highest salinities occurred during the late summer-fall period. In both 1974 and 1975, peak macrobenthic abundances occurred in August. There was no indication of a spring peak. Mediomastus and Streblospio were the numerically dominant species.

Clear Lake Studies

Mackin (1971) sampled the long axis of Clear Lake concomitant with the Trinity Bay studies. Salinities were 12-14 ppt in September and October 1970. Salinity decreased to 4 ppt in November, then increased to 20-24 ppt for the remainder of the study. Macrobenthic abundances increased from September 1970 (Figure VII.12) to a peak in January 1971 (Figure VII.13; note that the maximum scale abundance has been increased to 25,000 ind/m^2). A second peak occurred in June 1971. Mediomastus and Streblospio were the numerical dominants.

West Bay Area Studies

Several studies were conducted in the West Bay area (including bayous opening into West Bay) between 1967 and 1981. Data collected between 1982 and 1984, and from 1990 to the present (Figure VII.2), have been collected but not analyzed. In all the studies reported in this section, sampling was consistently done with an Ekman grab and samples were washed on a 0.5 mm mesh sieve. Three replicate samples were taken at each station. These West Bay studies included investigations of macrobenthos assemblages in Eckert Bayou, an arm of West Bay on Galveston Island (Potts 1978, Walker unpub.), a study of New Bayou, which opens into Chocolate Bay (Nance 1984, 1991), and a sandy shore study along the north side of Galveston Island on West Bay (Dent 1983).

In Eckert Bayou in 1976, salinities decreased from 29 ppt in August to a low of 15 ppt in December, coincident with rainfall (Potts 1978). Abundances of macrobenthos decreased from August to September and then increased through December (Figure VII.14; note that figures are scaled at a maximum of 35,000 ind/m^2). Streblospio and Mediomastus were numerical dominants.

In 1977 salinities increased from 15 ppt in Dec to 25 ppt in March. A brief decrease to 20 ppt in April was followed by a increase to about 35 ppt in July (abiotic data through July 1978 not included). Macrobenthic abundances peaked in March, decreased rapidly and were fairly low until October (Figure VII.15), when an increasing trend began again (Walker, unpub.). Streblospio and Mediomastus were dominant except during March and April when Apelisca abdita (Amphipoda) bloomed.

In 1978, macrobenthic abundances peaked in February, then declined through June (Figure VII.16). Streblospio was the continual dominant, but large blooms of Wapsa grandis (Oligochaeta), Ampelisca abdita and Corophium louisianum (Amphipoda) occurred in February through May.

In 1980, Nance (1984) began a macrobenthic study in New Bayou and Dent (1983) began a study on the West Bay shore of Galveston Island. Nance sampled a bayou with a strong salinity gradient. Salinities were nearly always 20-25 ppt at the downstream-most stations in Chocolate Bay, and nearly always about 1 ppt at the upstream-most station. Macrobenthic abundances underwent a gradual decrease through October, and then began increasing through the end of the year (Figure VII.17).

In 1981, Nance recorded salinities of 20-25 ppt until a heavy rainfall occurred in May. By late May, salinities at the Chocolate Bay stations had decreased to 11-15 ppt and by June, the entire bayou was essentially a freshwater habitat except near the mouth at Chocolate Bay where salinities were about 5 ppt. Salinities returned to near 25 ppt by August. Dent recorded salinities in the 25-30 ppt range from January to June. He recorded a decrease in salinity to 20 ppt in June, a month later than Nance. In July and August salinities were near 30 ppt, but decreased again in September to 17 ppt. By December, the salinity had increased to about 25 ppt. Nance recorded a February peak abundance, followed by a decline through early May (Figure VII.18). Following the

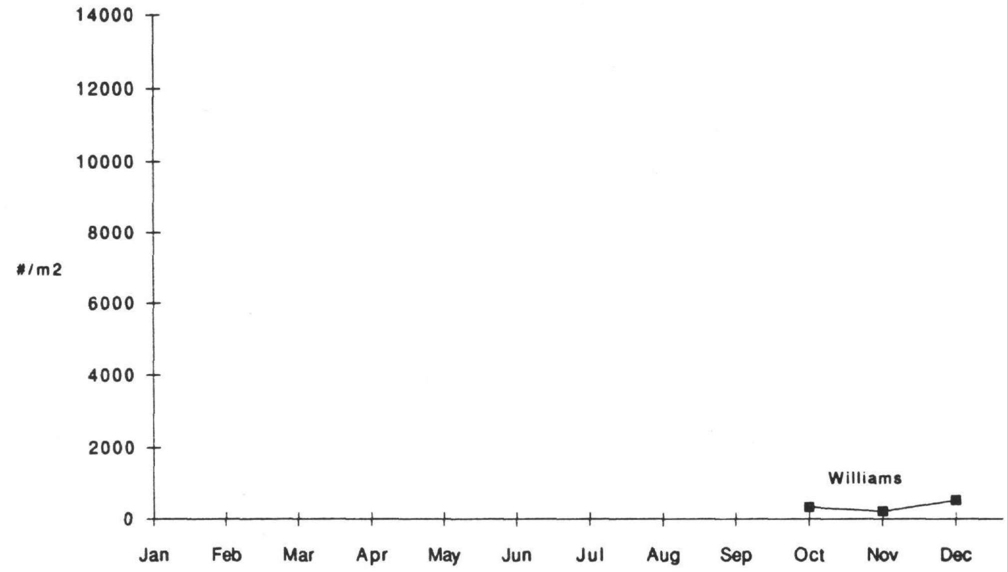

Figure VII.4. Trend of macrobenthic abundance in the Trinity Bay area in 1969.

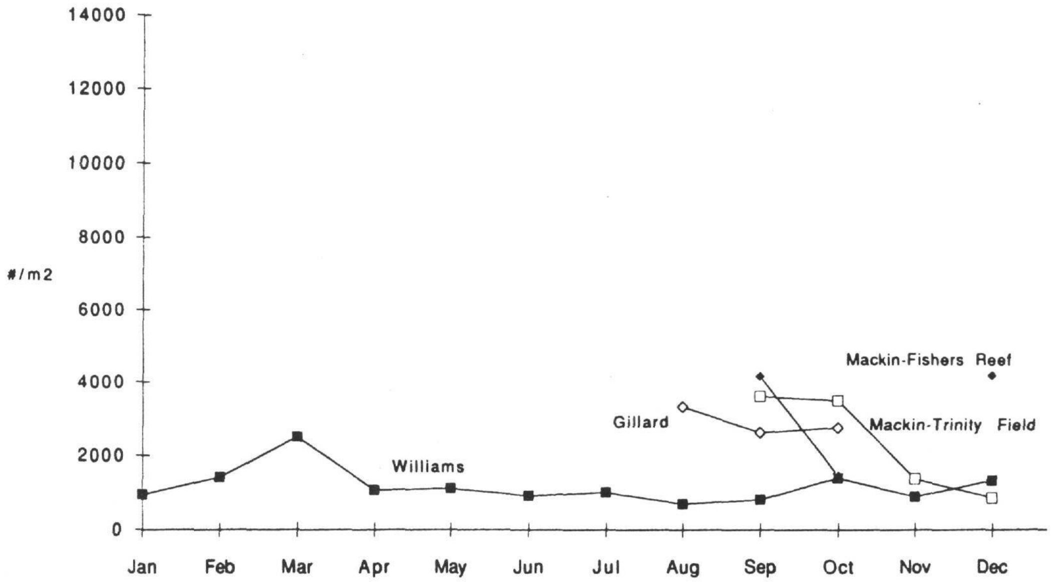

Figure VII.5. Trends of macrobenthic abundances in the Trinity Bay area in 1970.

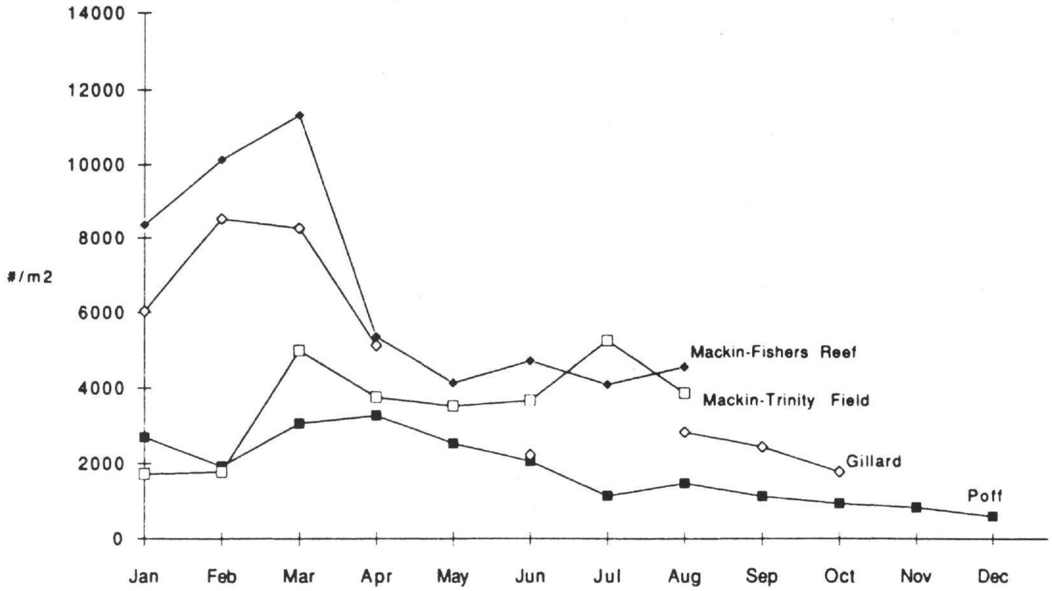

Figure VII.6. Trends of macrobenthic abundances in the Trinity Bay area in 1971.

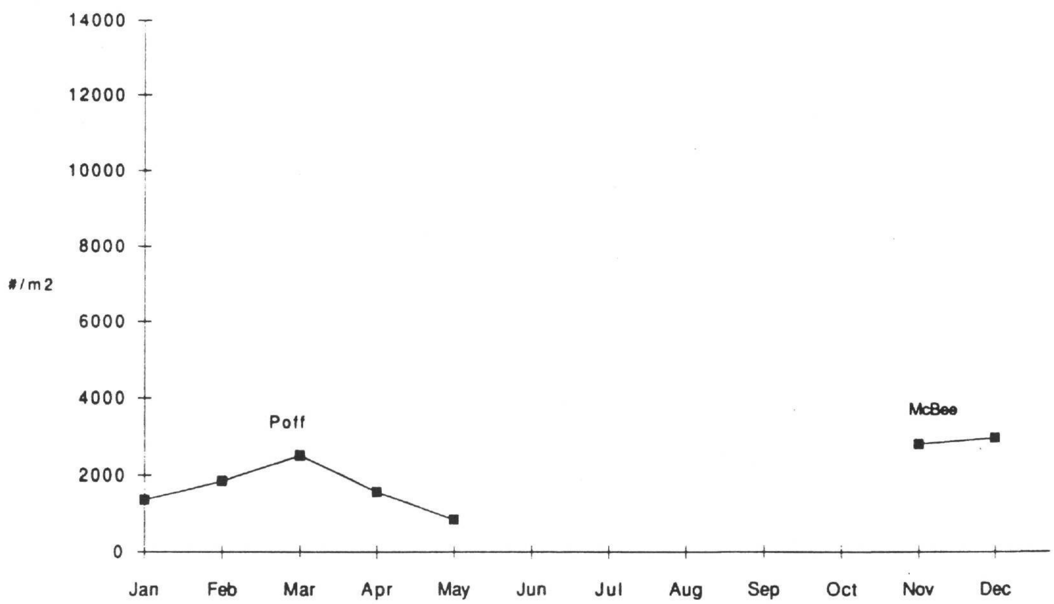

Figure VII.7. Trend of macrobenthic abundance in the Trinity Bay area in 1972.

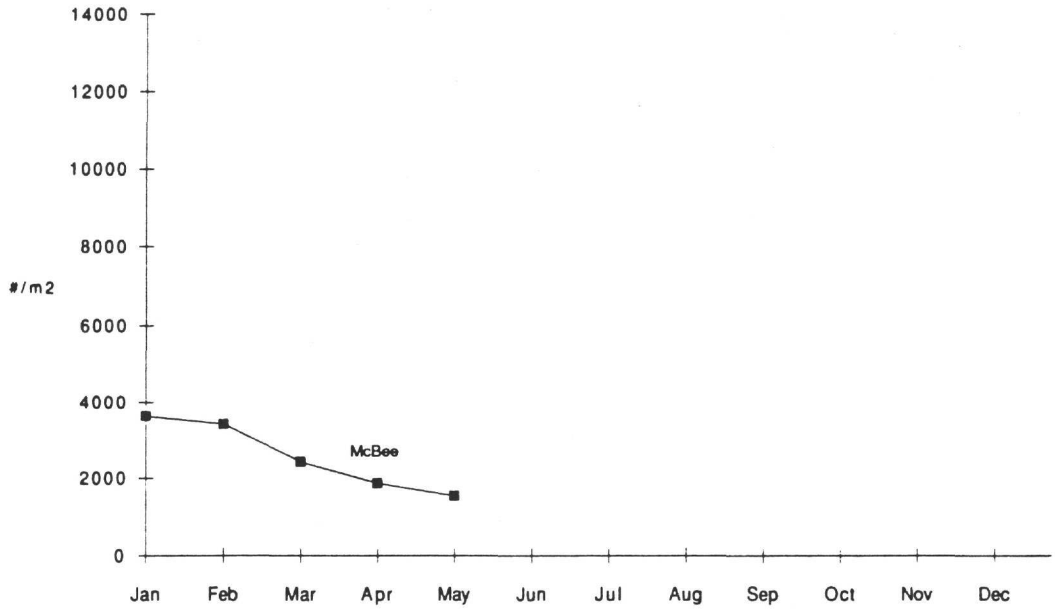

Figure VII.8. Trend of macrobenthic abundance in the Trinity Bay area in 1973.

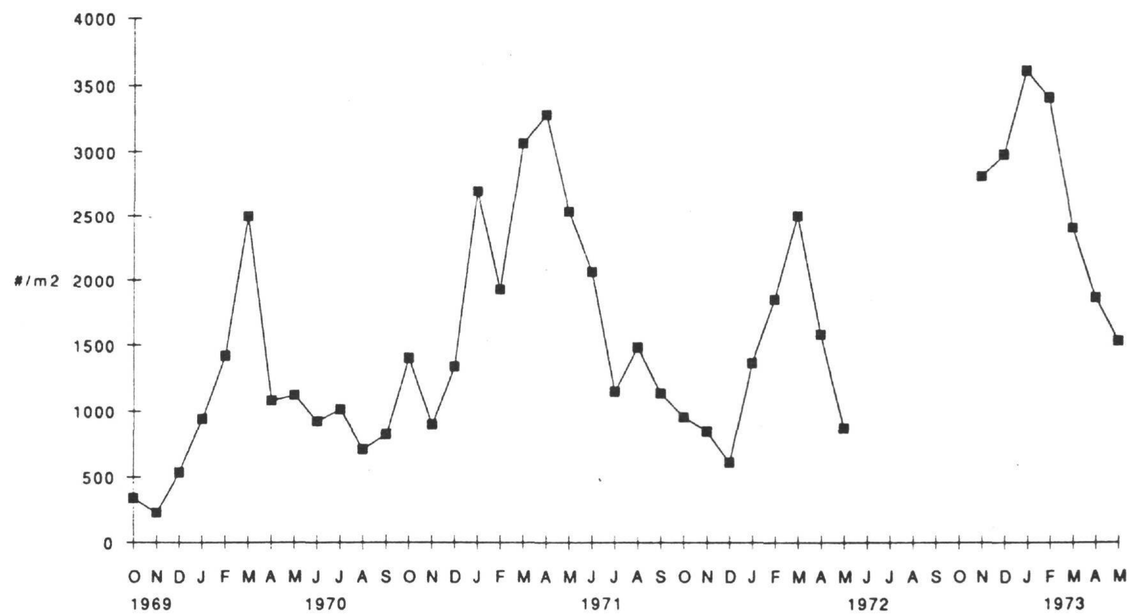

Figure VII.9. Trend of macrobenthic abundance in the Houston Lighting and Power project, 1969-1973.

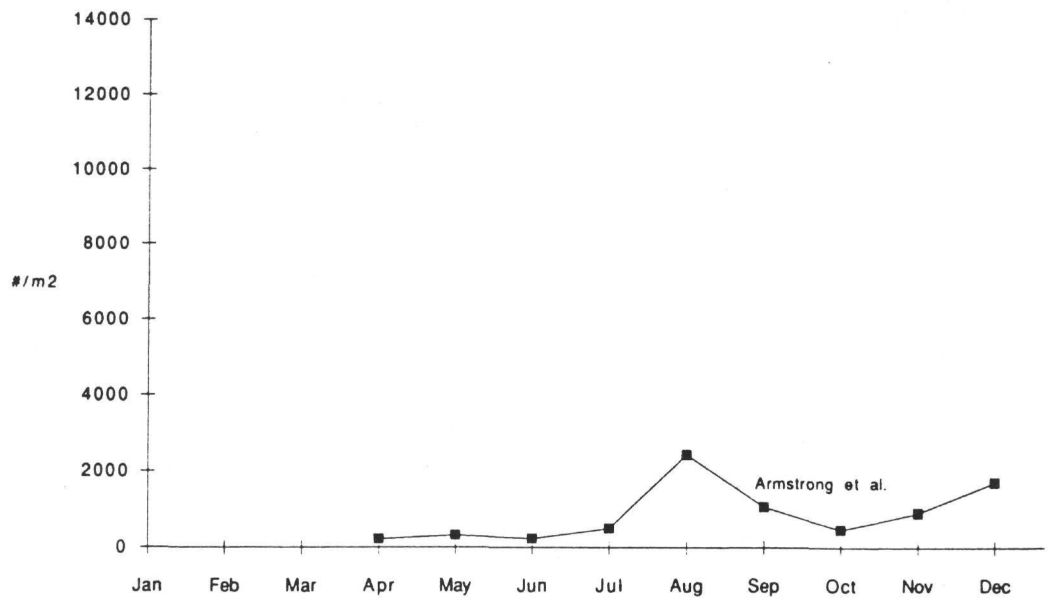

Figure VII.10. Trend of macrobenthic abundance in the Trinity Bay area in 1974.

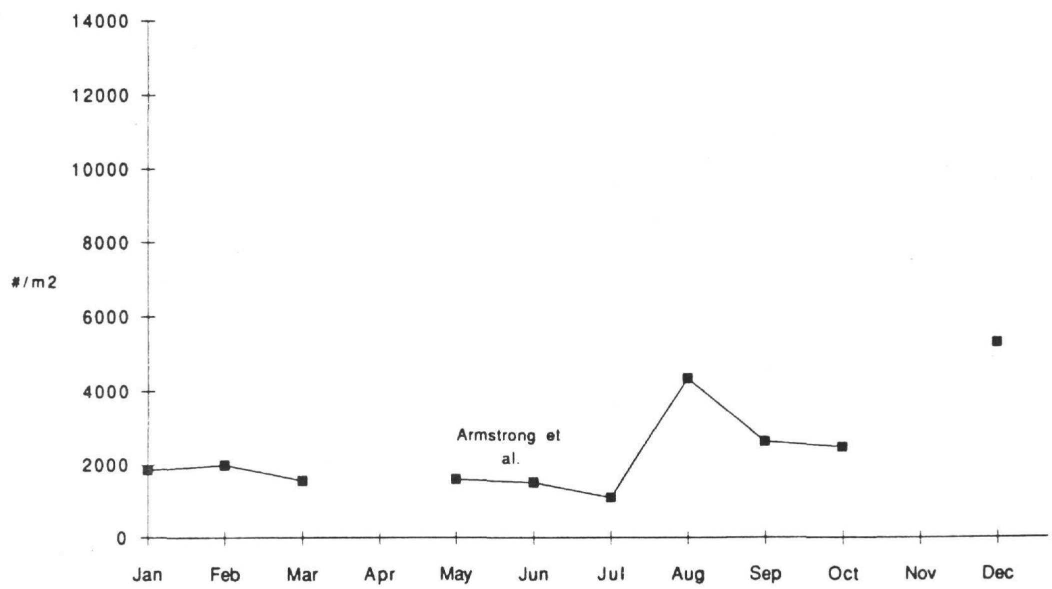

Figure VII.11. Trend of macrobenthic abundance in the Trinity Bay area in 1975.

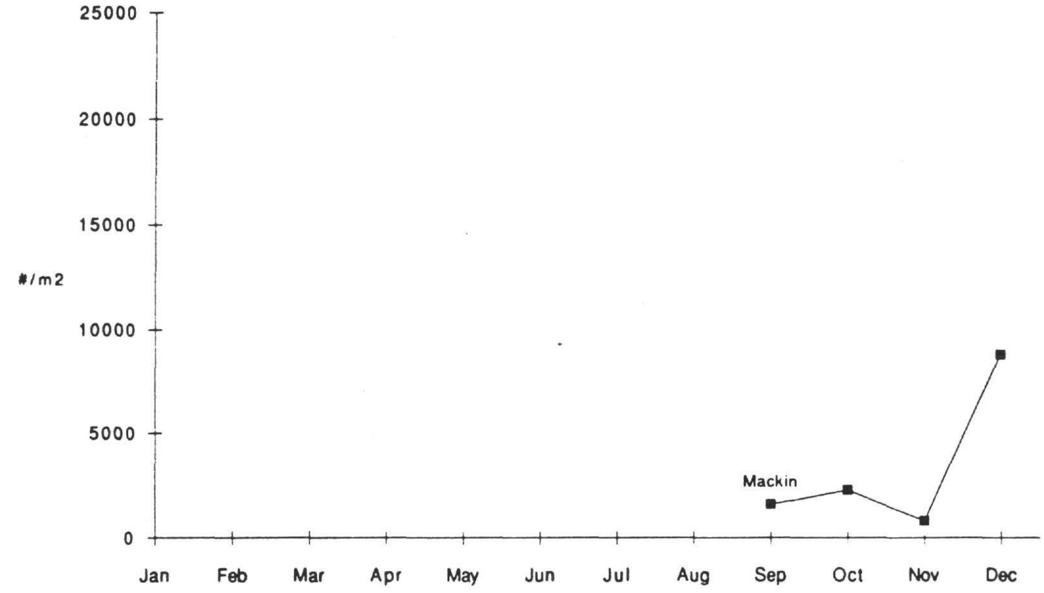

Figure VII.12. Trend of macrobenthic abundance in Clear Lake in 1970.

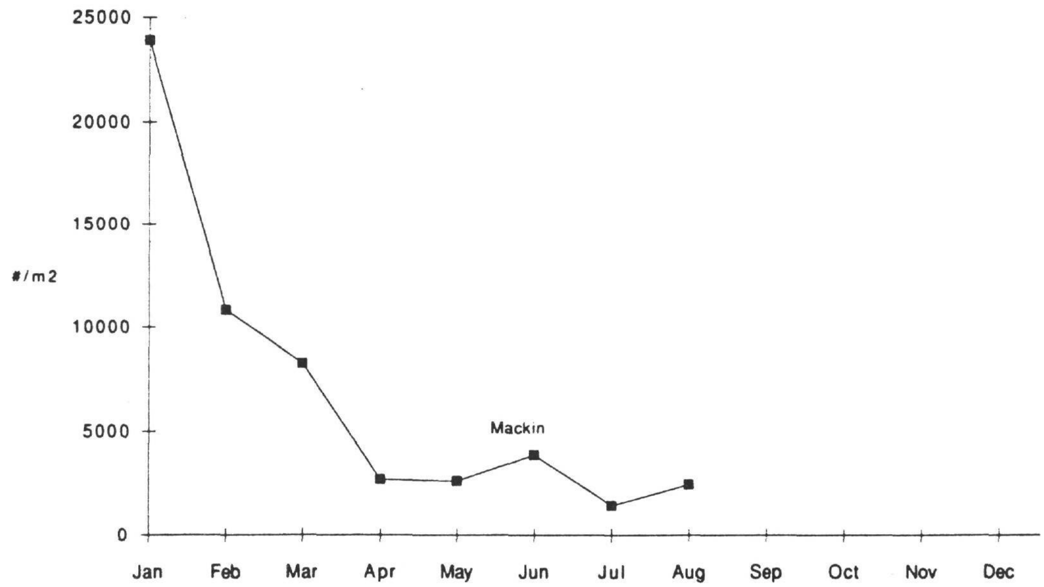

Figure VII.13. Trend of macrobenthic abundance in Clear Lake in 1971.

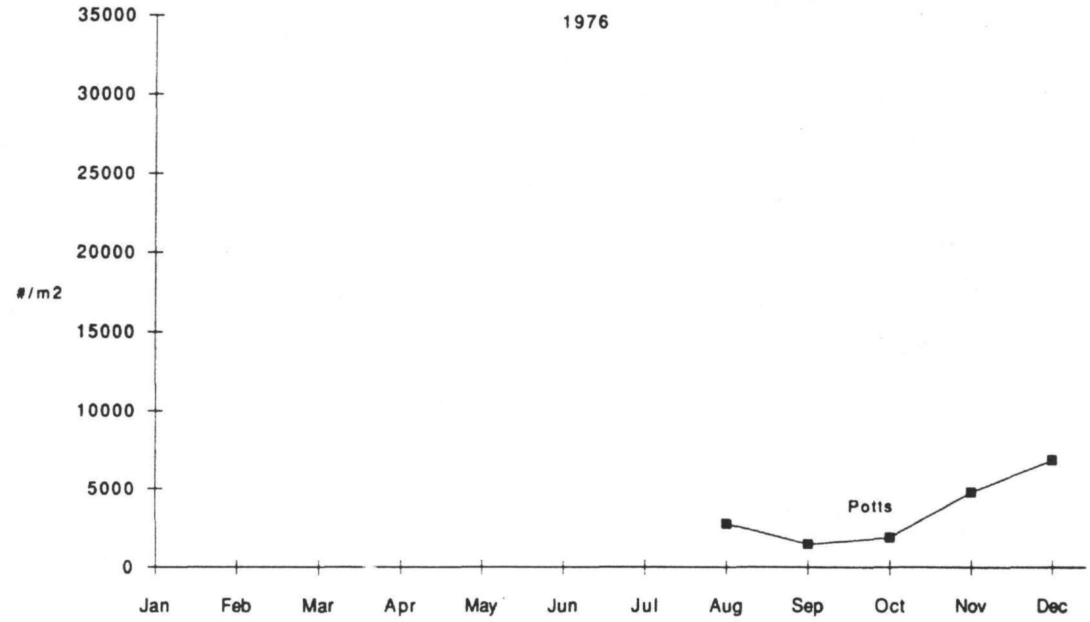

Figure VII.14. Trend of macrobenthic abundance in Eckert Bayou in 1976.

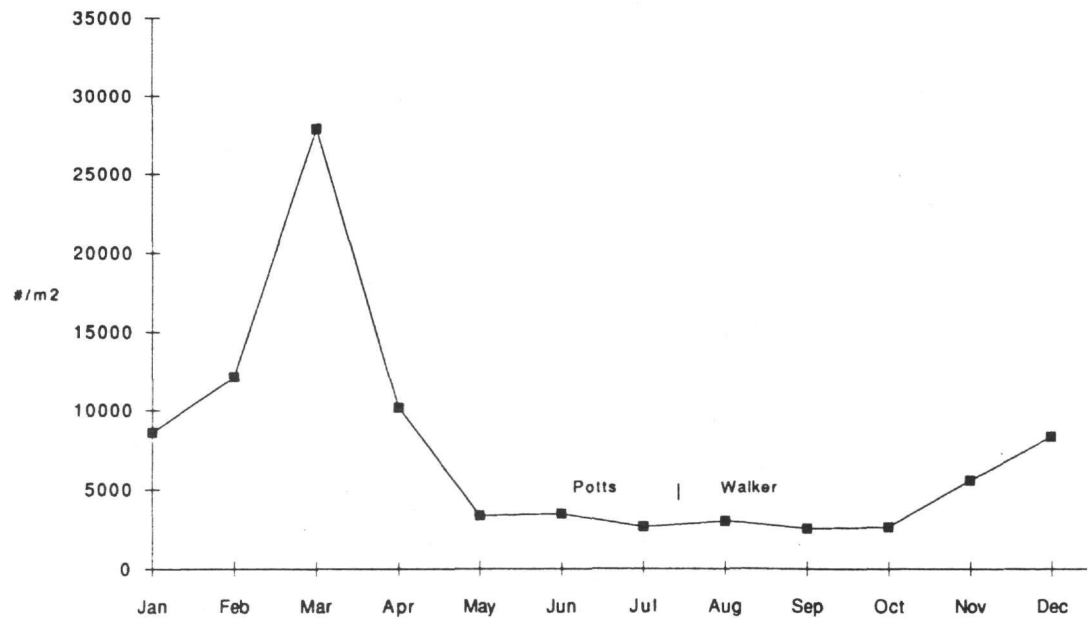

Figure VII.15. Trend of macrobenthic abundance in Eckert Bayou in 1977.

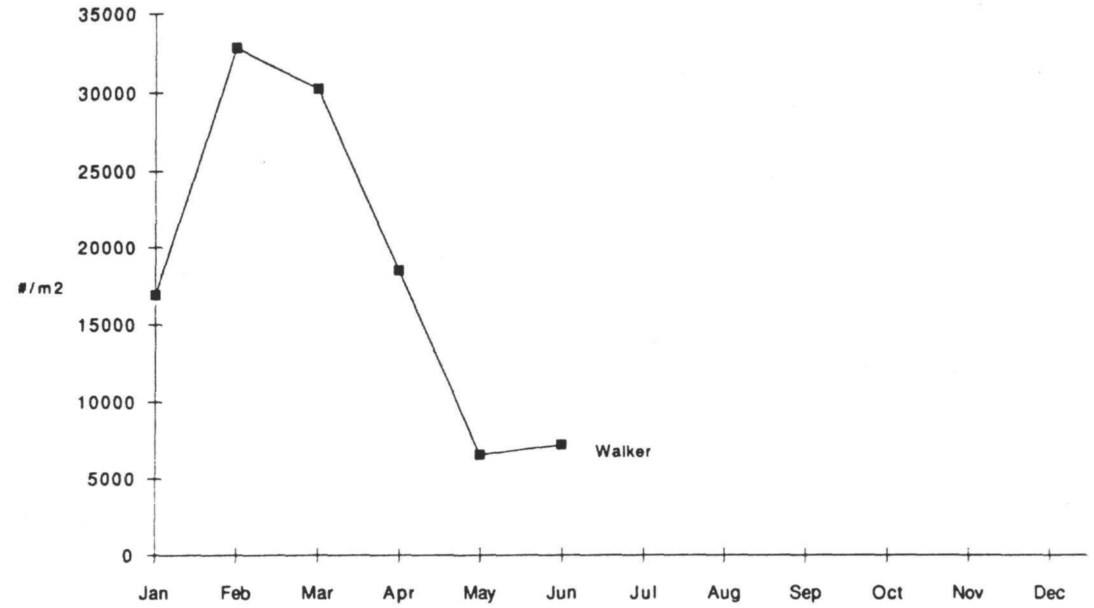

Figure VII.16. Trend of macrobenthic abundance in Eckert Bayou in 1978.

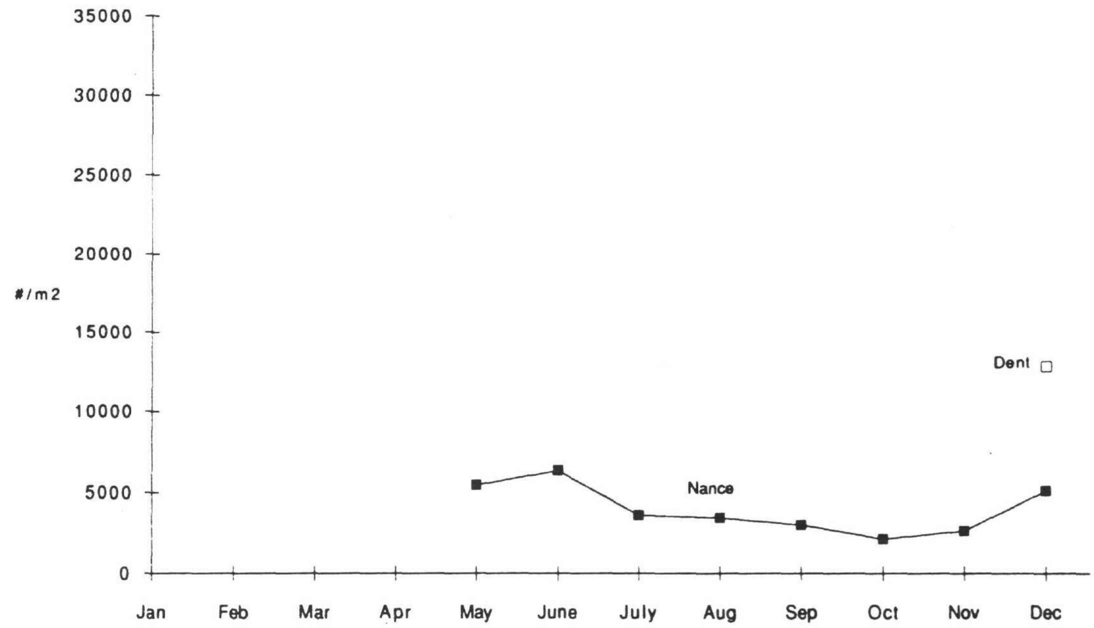

Figure VII.17. Trends of macrobenthic abundances in the West Bay area in 1980.

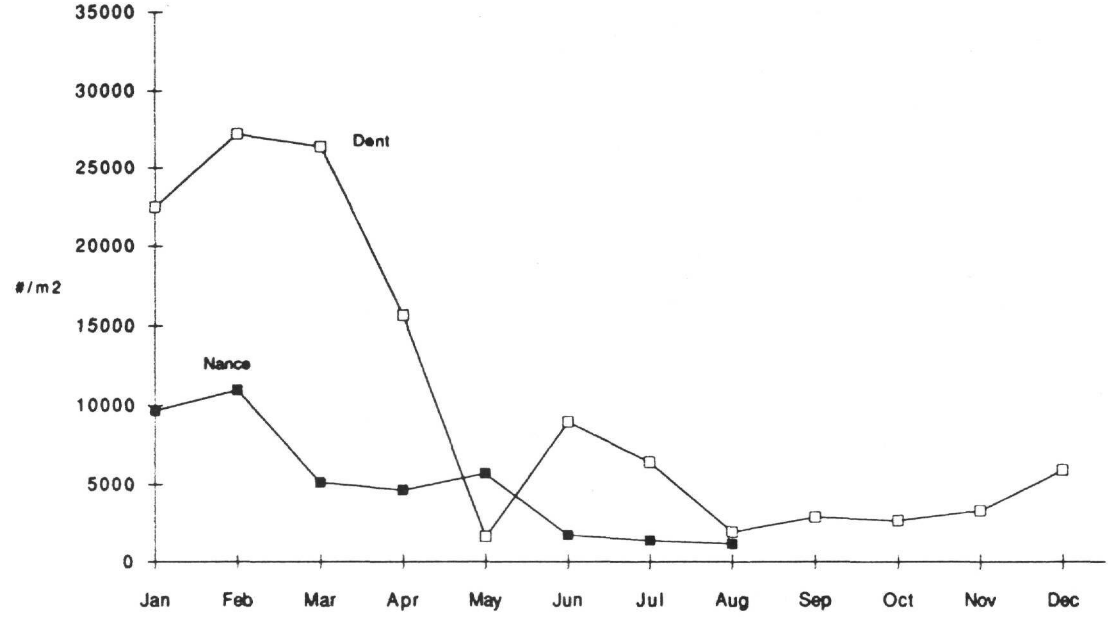

Figure VII.18. Trends of macrobenthic abundances in the West Bay area in 1981.

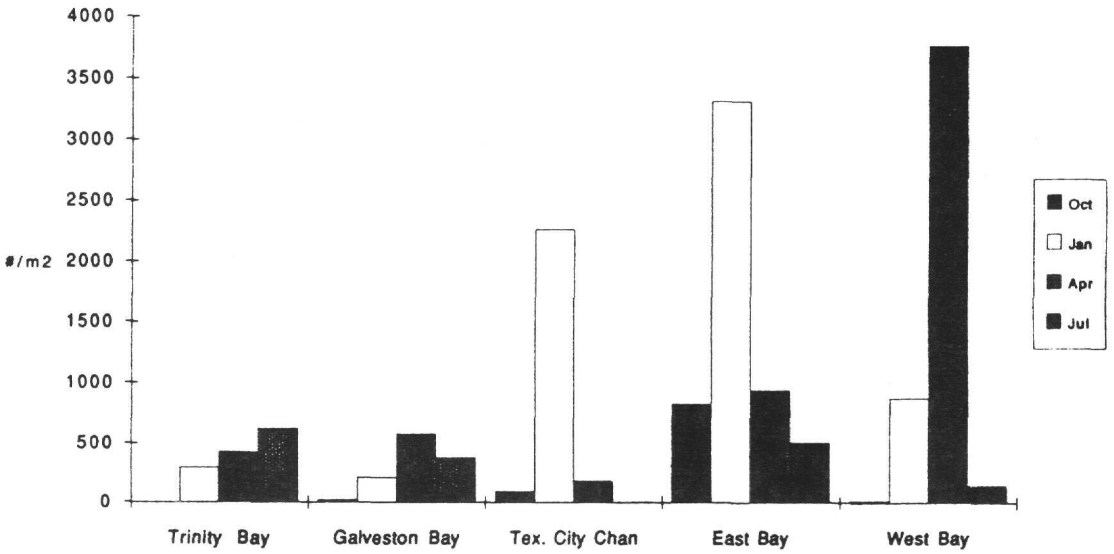

Figure VII.19. Comparison of quarterly macrobenthic abundances at five stations in the Galveston Estuary in 1971-72.

flooding event, a secondary peak occurred in late May, and then abundances decreased through December. Dent recorded a peak abundance in March, followed by a decrease in May (Figure VII.18). A secondary peak occurred in June (a month after Nance recorded a second peak), and then low numbers were collected through December. Five dominant species occurred in Nance's study: Mediomastus, Streblospio and Macoma mitchelli (Bivalvia) were dominants in the higher salinity region of the bayou, and Hobsonia florida (Polychaeta) and Tubifocoides heterochaetus (Oligochaeta) dominated the lower salinity region. Bayou flushing moved the lower salinity forms farther down-bayou for a short period of time. In Dent's study, Streblospio and Heteromastus filiformis (Polychaetea) were the dominant species. Mediomastus, Capitella capitata (Polychaeta) and Mulinia lateralis were lesser dominants.

Other Studies in the Galveston Estuary

Bechtel, Copeland and Whitefield (1970) attempted to assess the relationship between water quality and quantity of waste input and ecological response in the Galveston Estuary. Only one sample was collected at each station. Very few of the benthic species collected were identified and most of these were mollusks. Data were pooled for bay areas, but some stations were not sampled in each season and the data are misleading.

Mean benthos abundances increased from 46 ind/m^2 in February and decreased to 42 ind/m^2 in April, 15 ind/m^2 in July, and 12 ind/m^2 in October. Greatest overall abundances were in Trinity Bay and Upper and Lower Galveston Bay. The raw data indicate almost complete seasonal succession in each area; none of the species were common to all 4 collections and very few were common to 3 collections. Dominant taxa were Polychaeta and Mollusca. Because of the incompleteness (and questionableness) of identifications, numerically dominant species cannot be determined.

Holland, Masciolek and Oppenheimer (1973) conducted a quarterly study of the macrobenthos at 5 stations in the Galveston Estuary from 1971 and 1972. Freshwater inflow reduced salinities at all stations in January 1972. Salinities then increased through July 1972; the amount of decrease and increase depended on the location of the station within the estuary. Neither the Trinity Bay station nor the Galveston Bay station, both closest to the source of freshwater inflow, experienced major changes in total macrobenthic abundance (Figure VII.19). Large spring peak abundances occurred at the Texas City Channel, East Bay, and West Bay stations, where higher salinities were recorded. Note that relatively small numbers of individuals were collected. This study is least similar to most of the other studies because the investigators used a 1.5 mm mesh sieve to wash the samples.

Henry (1976) conducted a study offshore from the Galveston Estuary from May 1975 through April 1976. A 1 mm mesh screen was used to wash samples, which probably caused many of the smaller organisms to be lost. At the beginning of the study, in May and June 1975, salinities were in the 18 ppt range, but increased to about 30 ppt in July. Salinities ranged from 25 to 27 through February 1976, then decreased to 23 in March and April. At the beginning of the study, extremely large populations of Balanoglossus sp. (Hemichordata) were collected (Figure VII.20). This population disappeared quickly as salinities increased, and the total abundances through the remainder of the project were less than 500 ind/m^2. A small fall increase occurred in November 1975.

Fort (1983) sampled every three weeks in Laguna del Oro, a body of water created by dredging which opened to West Bay, from August 1980 to June 1981. An Ekman grab and 0.5 mm mesh sieve were used in the field. Salinities remained in the 27-32 ppt range throughout the study. Abundances decreased from August through November 1980 (Figure VII.21). A first spring peak occurred in January 1981 and a second in April, after which abundances decreased through June. Streblospio, Tharyx marioni (Polychaeta) and Capitella capitata were the numerical dominants.

Studies in the Sabine Area

Wern (1980) sampled in the Sea Rim State Park area in 1978 and 1979 (Figure VII.22). Salinities increased from 13 ppt in September to 19 ppt in December 1978, and thereafter were < 7 ppt. During the first three-quarters of the study, very large populations of Mediomastus and Streblospio at two stations in somewhat isolated lakes resulted in a macrobenthic abundance trend that was quite different from the trend seen if only data from the more interconnected stations are used (Figure VII.22). The dominance of these two species decreased steadily at the two isolated stations, and by May 1979, the total abundances were similar at all stations. There was very little evidence of a spring peak; if one occurred, it was in January or February.

Studies in the Lavaca-Matagorda Estuary

Mackin (1971) also conducted a study of brine discharges in the Lavaca-Matagorda Estuary. Salinities increased from 12-13 ppt in September 1970 to 29-30 ppt in June 1971. Macrobenthos abundances increased from September 1970 to a spring peak in February 1971 and then steadily declined through August (Figure VII.23). Total numbers of individuals were much lower in this study than in comparable studies in the Galveston Estuary. Mulinia lateralis and Mediomastus were the numerical dominants.

Gilmore et al. (1976) conducted a study of the benthos of Lavaca Bay in relation to freshwater inflow from 1973 to 1975. Mean salinities decreased from about 20 ppt in January 1973 to about 8 ppt in May coincident with high river discharge, and remained low until September. Salinities increased through the fall to about 20 ppt by December, then decreased to 10 ppt following high river discharge. Through all of 1974, the salinity alternately increased to about 18 ppt (March, August, December) and then decreased to about 10 ppt (May, September) following high river discharge. In 1975, the salinity increased to 20 ppt by March, then decreased to abut 3 ppt in May. Benthic abundances increased from a mean of 75 ind/m^2 in January 1973 to a May peak of 246 ind/m^2 (Figure VII.24). A second peak (262 ind/m^2) occurred in July and then abundances declined through the fall and winter. The 1974 spring peak (313 ind/m^2) occurred in May. In 1975, maximum spring abundances (214 ind/m^2) occurred in June. The changes in salinity did not appear to greatly affect benthic abundance trends.

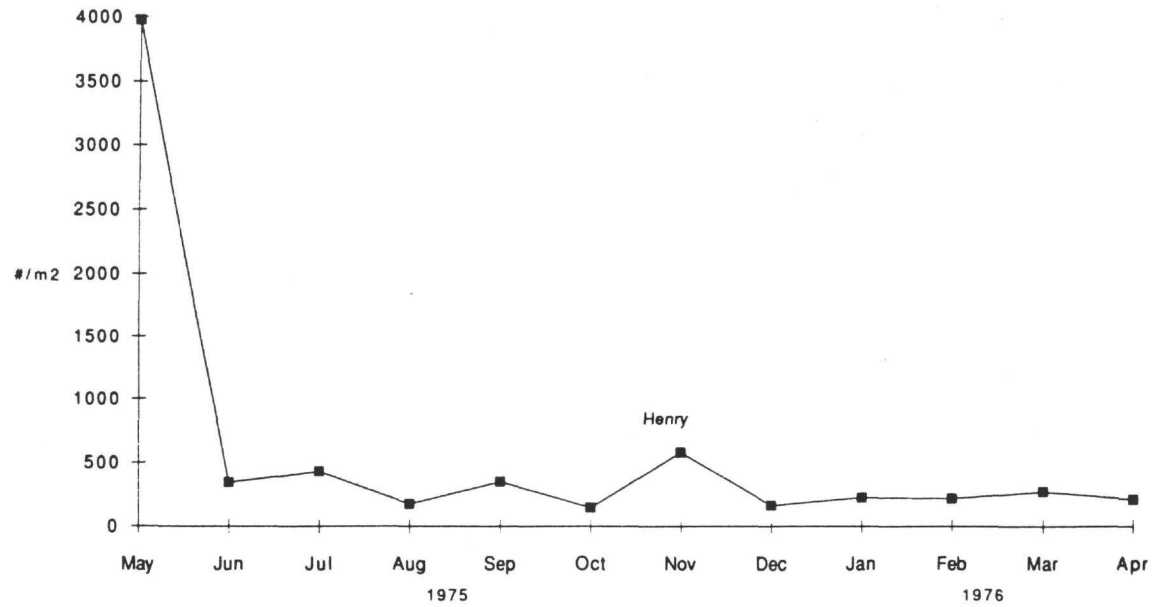

Figure VII.20. Trend of macrobenthic abundances in nearshore bottoms off Bolivar Roads in 1975-76.

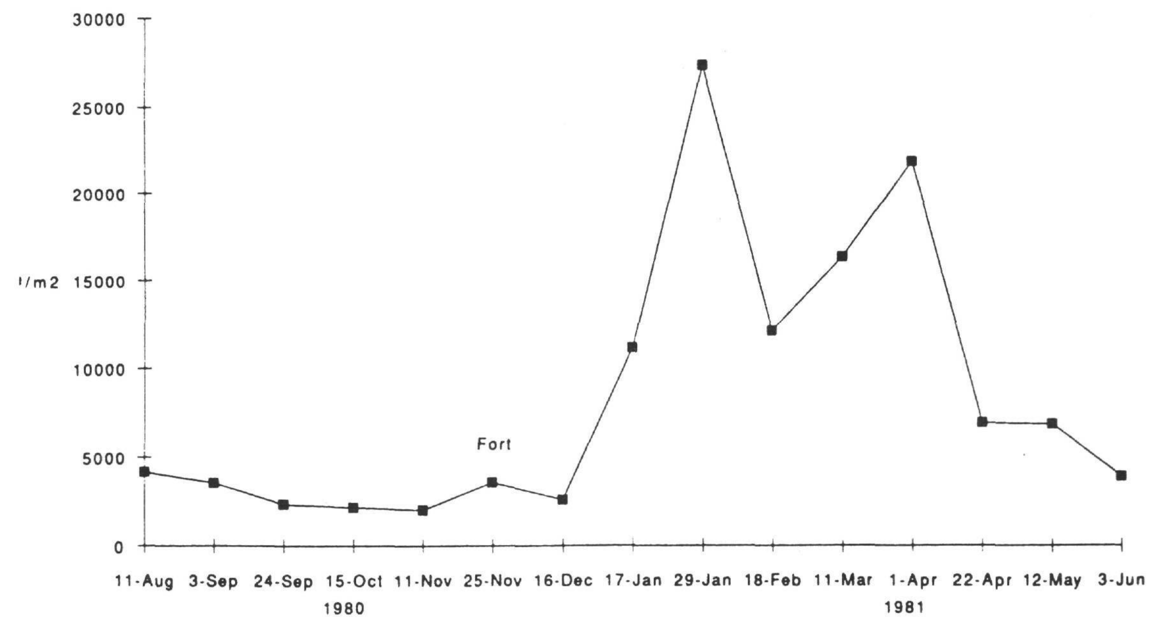

Figure VII.21. Trend of macrobenthic abundance in Laguna del Oro, West Bay area, in 1980-81.

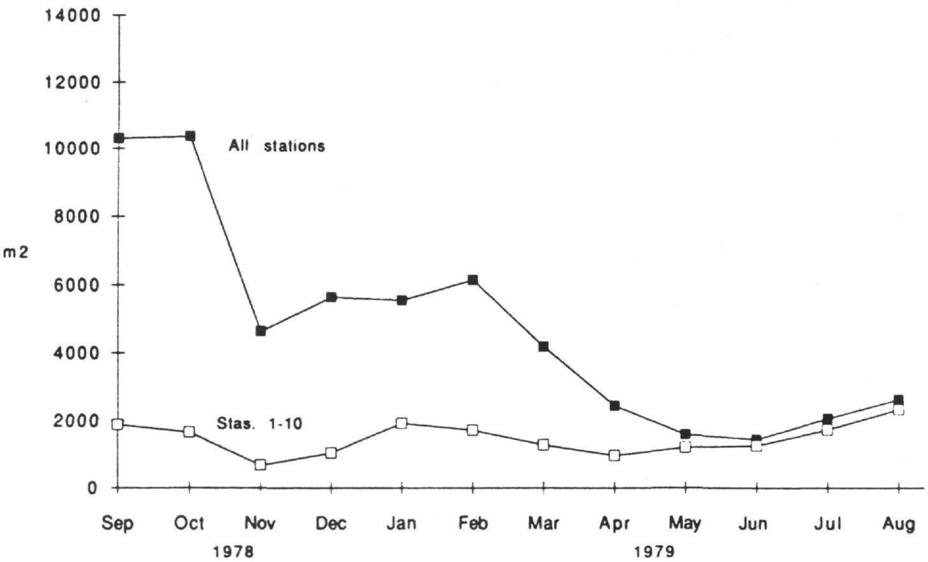

Figure VII.22. Trend of macrobenthic abundance in the Sea Rim State Park area in 1978-79.

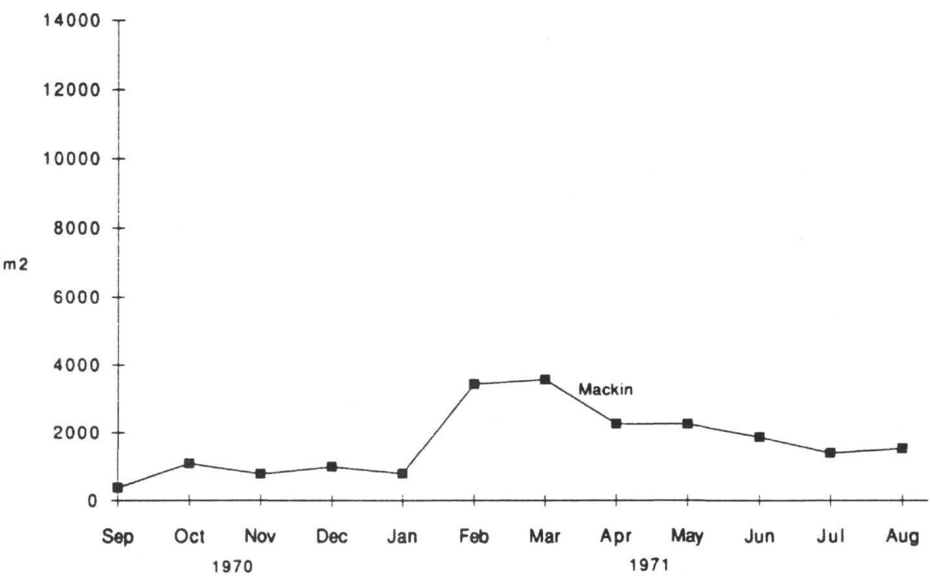

Figure VII.23. Trend of macrobenthic abundance in Lavaca-Matagorda Bay in 1970-71.

Studies in the San Antonio Estuary

Harper and Hopkins (1973, 1976) reported on macrobenthic assemblages in relation to dredging activities in San Antonio Bay in 1972-1973. A major flood on the Guadalupe River lowered salinities in the upper bay to near zero, and to about 5 ppt in the lower bay. Salinities gradually increased to about 15 ppt in the upper bay and 25 ppt in the lower bay. Macrobenthic densities in the upper bay decreased sharply during the flood, but increased again quickly in June (Figure VII.25). Abundances then underwent the usual decrease through October 1972 and then increased through February 1973. Numerical dominants were Mediomastus, Texadina sphinctosoma (Gastropoda) and Streblospio. Abundances in the lower bay, which were always lower than in the upper bay, changed very little during the study except for a decrease in numbers in August 1972. Matthews et al. (1974) also conducted benthic studies in San Antonio Bay, using essentially the same stations as Harper and Hopkins (1973 1976), and reported the same dominants, and also determined that abundances were higher in the upper bay than the lower bay (Fig 25). They reported abundances that were lower than those reported by Harper and Hopkins (1973, 1976) and the temporal trends did not correspond.

Distributions of Macrobenthos in Relation to Man-made Perturbations

Many of the macrobenthic studies have been conducted to determine the environmental effects of pollutants on the marine ecosystem. During the HL&P project, the investigators established stations in the intake and discharge areas of the plant, and in the near field and far field of the thermal effluent (Williams 1972, Poff 1973, McBee 1975). No effect from the effluent could be detected, and the investigators believed that the water quality of Cedar Bayou was improved because brine discharged upstream of the plant was being diluted by water being drawn upstream from the mouth of Cedar Bayou.

Studies on the effects of oil field brine discharges have all resulted in essentially similar findings (Mackin 1971, Armstrong et al. 1977, 1979, Nance 1984). An area around the discharge has hydrocarbons (especially naphthalenes) incorporated into the sediments, and these bottoms are virtually depauperate. Abundances of macrobenthos increase with increasing distance from the discharge, reaching a maximum at about 500-1500 m distance, then the abundances decrease to "normal" levels (Harper 1986).

Studies of the effects of oyster shell dredging in the San Antonio Estuary indicated that dredge holes filled quickly for 2-3 years, then at a slower rate (Harper and Hopkins 1973, 1976). Dredge holes that were 24 years old were still up to 0.4 m deeper than the surrounding undredged bottom. Newly created dredge holes contained soupy sediments, which required about 9 months to consolidate. Low numbers of macrobenthos occurred in newer holes. As the holes aged and filled, the numbers of individuals collected increased, but about 5 years were required to obtain near-normal levels of macrobenthos.

SUMMARY

Studies of benthic assemblages in the Galveston Estuary and in adjacent estuaries can be grouped into two major categories: those in which areal coverage is broad but sampling is infrequent, and those in which a relatively small area is sampled frequently. Most studies have been the latter type and have been used to provide information on point source and non-point source chemical contamination of sediments and organisms in various parts of the estuary.

The size of the sampler, the number of replicate samples, and the mesh size of the sieve used to remove sediments from samples have varied greatly. Some of the differences in total abundances reported by concurrent studies in a given region of the Galveston Estuary probably resulted from the investigators collecting different numbers of replicate samples, or using different sized sieves.

Benthic assemblages generally exhibited a spring peak abundance and a fall low, but a few studies documented a second peak in the fall. Spring peak abundances generally occurred between February and May, as water temperatures were increasing, and the fall low generally occurred in October-November. Freshwater flood conditions can alter the normal seasonal pattern. The macrobenthos can be very good indicators of salinity conditions, but there are not enough data among the studies reviewed to document long term changes in salinity gradients or circulation patterns.

Polychaeta, Mollusca and Crustacea were the usual dominant taxa. Typically, one or two species, usually Mediomastus ambiseta and Streblospio benedicti, were numerically dominant in the assemblage. In river-influenced assemblages, Texadina sphinctostoma, Hobsonia florida and chironomid insect larvae were often numerically dominant. The numerical dominants may be one or two orders of magnitude more abundant than the less abundant species, and therefore control the overall abundance trends of the assemblage.

There appears to be an abundance gradient in the Galveston Estuary in which numbers of individuals increase from the Trinity Bay-Upper Galveston Bay region to the Lower Galveston Bay-West Bay region. This is the reverse of the pattern found in the San Antonio Estuary by Matthews et al. (1973) and Harper and Hopkins (1973, 1976), and may reflect the more southerly location and overall higher salinity of the San Antonio Estuary. There also appears to be gradient in which abundances decrease from the Galveston Estuary south to the San Antonio Estuary.

In general, the existing open bay macrobenthic assemblage data do little to address the Galveston Estuary priority problems. The data sets are from scattered locations in the estuary, and most studies were not continued over a sufficiently long period to determine long-term changes.

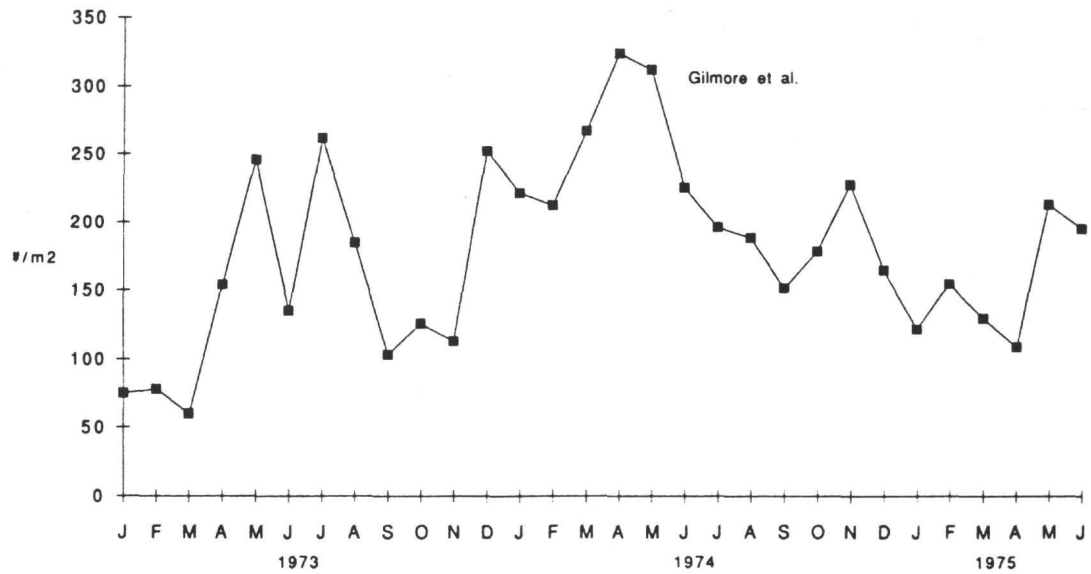

Figure VII.24. Temporal trend of benthic abundance in Lavaca Bay in 1973-75.

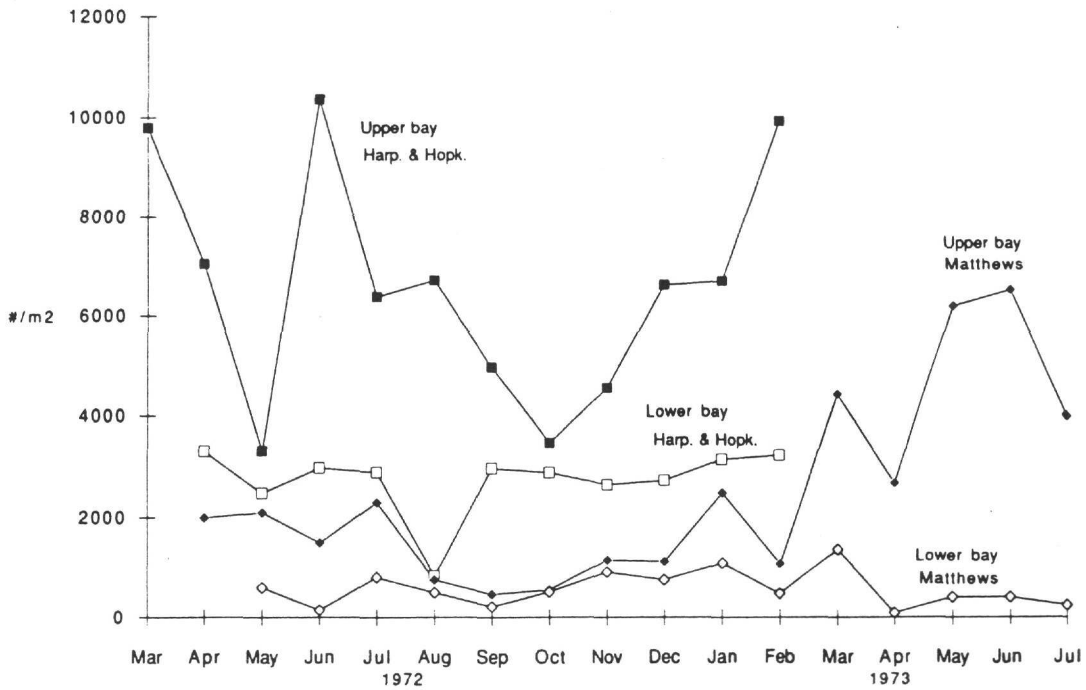

Figure VII.25. Temporal trends of macrobenthic abundances in upper and lower San Antonio Bay in 1972-73.

RECOMMENDATIONS

As noted above, very few benthic studies incorporate broad areal coverage and frequent sampling. The major problems with incorporating both aspects in studies of the Galveston Estuary involve logistics and personnel. The Galveston Estuary is quite large, and it is virtually impossible for one field crew to adequately sample the entire system in a sufficiently short time period to be certain that changes have not occurred in populations of macrobenthic species. Analysis of benthic samples is time-consuming, and requires individuals with at least some training in the taxonomy of polychaetes, mollusks and crustaceans (the dominant groups). If a comprehensive study of the Galveston Estuary is conducted, the benthic program should include widespread and frequent sampling. This type of program will require that at least three fully trained and equipped field/lab crews be available, and these crews should be dedicated to the Galveston Estuary and not be shunted to other programs. One crew should be assigned to sample Trinity Bay and Upper Galveston Bay, one to East Bay and half of Lower Galveston Bay, and one to West Bay and half of Lower Galveston Bay. Sampling should be conducted simultaneously in all three areas, and the entire sampling process should be completed in 4 days or less. All hydrographic and sedimentologic sampling should be conducted concurrently with benthic sampling. Only when truly synoptic data are collected and analyzed will areal and seasonal distributional patterns begin to emerge. Effective use of time series analysis requires fairly frequent sampling. Therefore, sampling should be conducted monthly. If this is not feasible because of funding limitations, monthly samples should be collected between January and June, so that the period of peak abundance is not missed. Another set of samples should then be collected in the late September - early October period.

Macrobenthic sampling equipment should consist of Ekman grabs and 0.5 mm mesh sieves. At least three replicate samples should be collected. Samples should be washed in the field and fixed in 5 percent buffered formalin. After a minimum of 24 hours in fixative, the samples should be washed and preserved in 70 percent rose bengal-stained ethanol; isopropanol should not be used because it hardens specimens. The Ekman grab is recommended because it samples a relatively small area (232 cm^2) and the individuals analyzing samples are not required to devote great amounts of time to sorting and identifying large numbers of dominant species, which may be at least one or two orders of magnitude more abundant than the other species. Three replicate samples provide a total of nearly 700 cm^2 of bottom, and also provide an estimate of variability of the assemblages at a particular site. The 0.5 mm mesh sieve retains macrobenthic organisms, but not meiobenthic organisms. Larger meshed sieves should not be used because most polychaetes, the most abundant taxon in most studies, are small and will not be retained by the sieve.

Sampling stations should be chosen from stations occupied for water quality sampling by the Texas Water Commission. This procedure was followed in selecting stations in the San Antonio Estuary, and very good macrobenthic distributional data were obtained (Matthews et al. 1974, Harper and Hopkins 1973, 1976). Additional stations can be added if the effects of particular discharges or disturbances are to be investigated.

Adequately trained personnel are necessary if the field data are to be translated into information that can be used by managers. Sample sorters who miss a large number of organisms greatly bias the study results. The individuals assigned to identify organisms must be competent in the identification of major taxonomic groups. Misidentification of species, while not affecting determination of seasonal or areal variability of entire assemblages, will cause substantial problems if one assemblage is compared with another, or if a detailed discussion of the species composition of an assemblage is attempted. Turnover in laboratory personnel should be minimized as much as possible to reduce variability in identifications. A voucher collection, verified by taxonomic authorities, should be maintained at the laboratory where the work is being done so that if the identity of a newly collected specimen is questioned, it can be compared with known specimens. The voucher collection can also be used to acquaint new personnel with the fauna. Finally, the samples must be archived so that future investigators can reexamine specimens to be certain that everyone is applying the same name to the same species.

A sampling program that incorporated frequent broad coverage sampling will provide data that can be used to address components of two of the four priority problems of the Galveston Estuary, i.e. the Reduction/Alteration of Living Resources priority problem (loss of physical habitat, alteration of salinity gradients, bathymetric and circulatory changes, eutrophication and hypoxia, point and non-point sources), and Public Health Issues (chemical contamination of water, sediments and living organisms).

One of the causes of loss of level bottom, open bay habitat is the perception that these are relatively "dead" bottoms compared with reefal structures, and that the bottom can be made more productive by creating various high profile structures. The benthos sampling program can document that there are large populations of small organisms inhabiting open bay bottoms and that the open bay bottom is valuable in and of itself (research currently being done suggests that these organisms are heavily preyed upon by nektonic species). Many macrobenthic species are sensitive to changes in salinity conditions, and can act as indicators of alterations of salinity gradients and circulation. It has been demonstrated that there are several species that inhabit low salinity environments and will move downbay under flood conditions and retreat upbay as salinity increases. Under normal conditions, these species will be present in the upper bay periodically. Long-term absence of these species may indicate alteration of freshwater inflow and or circulation patterns. Conversely, the appearance of species which normally inhabit offshore bottoms, i.e. Mediomastus californiensis, Neanthes micromma, and others, in the lower or middle bay may indicate the intrusion of high salinity water. These species may be especially valuable in monitoring salinity intrusion along the Houston Ship Channel.

Point source chemical contamination of sediments and organisms can be studied by sampling the macrobenthos along transects extending away from the source. Abundances of macrobenthos usually respond strongly to substance input by either developing very large populations of a few tolerant species or by being unable to inhabit the area and creating a "dead zone," depending on the substance being discharged. Non-point sources can depress or alter assemblages over a very large area, and this type of pollution is likely to be detected by a long-term general monitoring study.

The sampling program will not provide quick answers to managers' questions or quick solutions to priority problems. Macrobenthic and other biological systems are inherently highly variable (e.g. the spring peak abundance usually occurs between February and May, but can occur in January or June) and there will be considerable "noise" in the data that must be filtered out before true patterns emerge.

Establishing a comprehensive sampling program will provide data from the project's inception into the future. If only these data are analyzed, it will be several years before enough data are collected to begin to determine patterns of organismal or assemblage abundance changes in relation to changes in abiotic characteristics or human perturbations. This program will provide no information on prior changes in the assemblages. Fortunately, data sets exist that cover periods dating back to 1972.

Data collected by the Texas Water Commission (unpub.) is a source of considerable information on long-term temporal changes in macrobenthic biota. Water Commission personnel began sampling in the Estuary in 1972 (Table VII.2). Only 4 stations have been sampled at least once a year since the inception of the project, i.e. Trinity Bay near Exxon C1 platform, Galveston Bay near Redfish Island, and West Bay at Carancahua Reef. However, about 7 stations were sampled over a 10-12 year period before being discontinued, and several were in areas considered to be polluted or stressed, i.e. the ship channel stations. These stations should be reestablished when a sampling program to monitor the Estuary is begun. Furthermore, funding should be provided to permit analysis of the backlog of samples and data currently at the Water Commission Laboratory.

A second source of considerable information on long-term temporal changes exists in the Eckert Bayou study. Eckert Bayou is a microcosm of the West Bay area. It has bottoms of sand, mud, and mud with detritus, and the assemblages characteristic of each bottom type. Monthly sampling began in 1975, and ended temporarily in 1984. The project was reestablished in 1990 and bimonthly sampling continues. Data from 1975-1977 have been analyzed. The remainder of the samples have been stored in the Texas A&M Marine Laboratory. Funding should be provided to complete the analysis of these samples, which will provide a continuous data set with which to evaluate long-term changes in assemblages, and for comparison with other, less continuous, data sets.

Abiotic data collected with both of the above studies include water temperature, salinity and dissolved oxygen as well as sediment characteristic. Analysis of both of these data sets should provide information on the overall changes which have occurred in the Galveston Estuary in relation to naturally occurring events and man-induced perturbations.

Table VII.2. Frequency of sampling at Texas Water Commission stations within the Galveston Estuary and the Brazos River.

SAMPLING STATION	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
Brazos River, State Hwy 36	1	2	1		1	2	3				1									
Trinity Bay, Anahuac Chan. Mark. 1		3	4														2	4	3	
Trinity Bay, Exxon C1				2	1	4	4	2		2	3	3	4	1			2	4	6	5
Trinity Bay, HL&P Cedar Bayou outfall		1	4	1																
Houston Ship Chan., Turning Basin		1	4	4	3	1	2	4	4	4	2	2	4	3						
Houston Ship Chan., Monument	3	3	4	4	4	4	5	4	4	4	2	2	4	1						
San Jacinto River at IH10	3	2	3	1	2	1	4	1												
Houston Ship Chan., Morgans Pt.	3	3	4	4	4	3	5	4	5	3	4	2	3							
Galveston Bay, 5 mi. pass																	2	4	6	
Galveston Bay, Seabrook Channel	1	3	4	2	2	4	4	1		2	1						2	4	3	
Clear Lake, Channel Marker 17		3	4	2	3	4	4	4	4	4	4	3	4	1						
Clear Lake, Mud Lake Bridge					4	4	4	2												
Clear Lake, Glen Cove					3	4	4	2												
Galveston Bay, near Redfish Reef	2	2	4	4	3	2	4	4	4	4	7	4	3	1		2	4	5	6	
Moses lake, Chan. Marker 9 (or 20)		1	4	2	2	3	4	2		1	1	1	1							
East Bay, Rollover Pass																	2	3		
East Bay, 8 km E Rollover Pass		1	4	4	4	3	4	2		1	2	2	1	1					2	
East Bay, Hanna Reef											1			1			2	4	5	3
Texas City Channel, Pump Canal				2		3	4	1		1			1							
Texas City Channel, Buoy 12		1	4	2	2	3	4	2		2	1									
Galveston Channel, Marker 2	1	4	2	2	4	3	2		1				3	2						
West Bay, Carancahua Reef		1	4	4	5	4	5	2	6	3	9	3	4	1	1		2	4	5	4
West Bay, Dana Cove																	2	4	2	
West Bay, San Luis Pass																	2	4	1	
Chocolate Bayou at FM 2004										1	5	1	3	1						
Chocolate Bay, Chan. Marker 9	2	3	3	2	2	4	4	1		1	5	1	3	3						
Christmas Bay		1	3	3	2	2	3	2			1						2	4	1	
Gulf of Mexico, Buoy 6				1	1															

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